Substituting into the equilibrium expression we get

$$0.42 = \frac{(s)(s)}{(0.010)^4}$$

$$s^2 = 4.2 \times 10^{-9}$$

$$s = 6.5 \times 10^{-5}\ M$$

You can see that not all complex ion formation leads to increased solubility. The molar solubility of CdC_2O_4 in water is 1.2×10^{-4}.

b. Determine the molar solubility of CdC_2O_4 in 5.0 M NH_3 and compare with the solubility obtained above with 0.010 M NH_3. **(E12)**

c. How many grams of AgBr can be dissolved in 1.0 L of 2.5 M NH_3? AgBr in NH_3 forms $Ag(NH_3)_2^+$. Compare with the mass of AgBr that can be dissolved in 1.0 L of pure water. **(E13)**

SELF-TEST

A. Multiple Choice:

1. The solubility product constant K_{sp} of Ag_2CrO_4 is related to its solubility in water as K_{sp} =

a. s^2 **b.** s^3 **c.** $4s^3$ **d.** s **e.** none of those

2. The solubility product expression for $Zn(CN)_2$ is

a. $[Zn^{2+}][CN_2^-]$ **b.** $[Zn^{2+}][CN^-]^2$ **c.** $[Zn^{2+}][2\ CN^-]$ **d.** $[Zn^{2+}][2\ CN^-]^2$

3. In which of the solutions listed below is AgCl least soluble?

a. pure water **b.** 0.20 M $CaCl_2$ **c.** 0.20 M $AgNO_3$ **d.** 0.20 M NaCl

4. Which carbonate would be the first to precipitate from a solution of 0.1 M in metal cation as CO_3^{2-} is added?

   a. $BaCO_3$ ($K_{sp} = 2.6 \times 10^{-9}$) **b.** $CaCO_3$ ($K_{sp} = 4.9 \times 10^{-9}$)
   c. $FeCO_3$ ($K_{sp} = 3.1 \times 10^{-11}$) **d.** $MgCO_3$ ($K_{sp} = 4 \times 10^{-6}$)

5. Addition of an aqueous solution of KCN to an aqueous solution of $NiCl_2$ results in the formation of a solid which dissolves upon addition of more KCN (aq). Which of the following statements is the most probable explanation for these observations?

   a. Ni^{2+} forms $Ni(CN)_2$ (s) and then forms $Ni(CN)_4^{2-}$.
   b. KCl (s) is formed then reacts with additional CN^- to give ClCN (aq).
   c. $Ni(OH)_2$ (s) forms and then dissolves as $KNi(OH)_3$.
   d. $Ni(CN)_2$ (s) forms but goes back into solution because addition of KCN makes the resulting solution more dilute and hence unsaturated.
   e. none of these

B. True or False:

What happens when 50.0 mL of 0.050 M $BaCl_2$ is added to 50.0 mL of 0.10 M K_2SO_4?

_____ **1.** KCl will precipitate.

_____ **2.** The inital concentration of Ba^{2+}, $[Ba^{2+}]_o = 0.025$ M after the two solutions are mixed, but before reaction occurs.

_____ **3.** If $[Ba^{2+}]_o \times [SO_4^{2-}]_o > [Ba^{2+}]_{eq} \times [SO_4^{2-}]_{eq}$, then precipitation occurs.

_____ **4.** $[Cl^-]_{eq} = [K^+]_{eq} = 5.0 \times 10^{-2}$ M

Consider $PbCl_2$. When it dissolves, the following reaction takes place.

$$PbCl_2\,(s) \rightleftharpoons Pb^{2+}\,(aq) + 2\,Cl^-\,(aq) \qquad \Delta H^\circ > 0$$

_____ **5.** $PbCl_2$ can be dissolved by a strong acid.

_____ **6.** $PbCl_2$ can be at least partially dissolved by a strong base if $Pb(OH)_4^{2-}$ exists.

_____ **7.** It is easier to dissolve $PbCl_2$ at higher temperatures.

_____ **8.** The molar solubility of $PbCl_2$ (s) in pure water can be expressed as $2s^3$.

C. Fill in the blanks:

Consider a saturated solution of $M(OH)_2$ where M^{2+} is a metal cation. Dissolving $M(OH)_2$ in water is an endothermic process. On the blanks provided, write **P** if a precipitate forms and **NP** if no precipitate forms when the saturated solution is subjected to:

_____ **1.** The addition of MCl_2 solution where M^{2+} is the same metal cation

_____ **2.** The addition of HCl

_____ **3.** An increase in temperature

_____ **4.** The addition of water

_____ **5.** The addition of ammonia to form $M(NH_3)_4^{2+}$

D. Problems:

Consider manganese sulfide, MnS, and tin(II) sulfide. Manganese sulfide has a K_{sp} of 5×10^{-14}. The solubility of tin(II) sulfide is 2×10^{-14} mol/L.

1. Calculate the K_{sp} of tin(II) sulfide.

2. How many milligrams of MnS can be dissolved in enough water to make 10.0 L of solution?

3. Calculate $[S^{2-}]$ if $[Mn^{2+}]$ is 2×10^{-5}.

4. Will a precipitate form if 0.500 mol of Mn^{2+} are added to one liter of a solution containing 0.0010 mol of S^{2-} ions?

5. In a solution that contains 1.00×10^{-4} mol of Mn^{2+} and 1.00×10^{-4} mol of Sn^{2+}, which will precipitate first when 1.00×10^{-10} mol S^{2-} is added?

6. Calculate the molar solubility of MnS in 0.3 M H^+ and 0.2 M H_2S. Assume that for the reaction

$$MnS\,(s) + 2\,H^+\,(aq) \rightleftharpoons Mn^{2+}\,(aq) + H_2S\,(aq)$$

K is 5×10^6.

Consider copper. The K_{sp} for CuCl is 1.7×10^{-7}. The K_f for $CuCl_2^-$ is 1×10^5.

7. Write the equation for the reaction between a solution of $CuNO_3$ and NaCl where a precipitate of CuCl is obtained.

8. At what concentration of NaCl will precipitation occur if NaCl is added to a 0.10 M solution of $CuNO_3$?

9. Write the equation for the formation of $CuCl_2^-$ from the reaction between CuCl and additional aqueous NaCl.

10. What is K for the reaction in (9)?

11. Compare the molar solubility of CuCl in pure water to that in aqueous 2.0 M NaCl where $CuCl_2^-$ is formed.

ANSWERS

Exercises:

(E1) $K_{sp} = [Ni^{2+}][Cl^-]^2$; $K_{sp} = [K^+][MnO_4^-]$ **(E2)** 9.0×10^{-5}

(E3) $[OH^-] < 4 \times 10^{-5}$ M gives an unsaturated solution
$[OH^-] = 4 \times 10^{-5}$ M gives a saturated solution
$[OH^-] > 4 \times 10^{-5}$ M gives a supersaturated solution

(E4) yes, $Ca_3(PO_4)_2$

(E5) 6.7×10^{-3} M; BaF_2 first **(E6)** 9.6×10^{-9}

(E7) 2 mg **(E8)** 0.0019 g/L; 0.74 g/L

(E9) $Ca_3(PO_4)_2$; 4×10^{-11} M

(E10) $Fe(OH)_3\,(s) + 3\,H^+\,(aq) \rightarrow Fe^{3+}\,(aq) + 3\,H_2O$; $K = 3 \times 10^3$

(E11) 5×10^6 M **(E12)** 16 M

(E13) 1 g in NH_3 ; 0.1 mg (1×10^{-4} g in water)

Self-Test

A. Multiple Choice:

1. c **2.** b **3.** b **4.** c **5.** a

B. True or False:

1. F **2.** T **3.** T **4.** F **5.** F
6. T **7.** T **8.** F

C. Fill in the Blanks:

1. P **2.** NP **3.** NP **4.** NP **5.** NP

D. Problems:

1. 4×10^{-28}
2. 0.2 mg
3. 3×10^{-9}
4. yes
5. SnS
6. 2×10^6 M
7. $Cu^+\,(aq) + Cl^-\,(aq) \rightleftharpoons CuCl\,(s)$
8. 1.7×10^{-6} M
9. $CuCl\,(s) + Cl^-\,(aq) \rightleftharpoons CuCl_2^-\,(aq)$
10. 2×10^{-2}
11. in pure water: 4.1×10^{-4} M
in 2.0 M Cl^-: 4×10^{-2} M